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## Issues of induction sorting of scrap and waste of non-ferrous metals

M E Zyazev<sup>1</sup>, E S Lyampasova<sup>1</sup>, Z O Abdullaev<sup>2</sup> and A Yu Konyaev<sup>3</sup>

<sup>1</sup> Master Student, Chair of Electrical Engineering and Electrotechnological Systems, Ural Federal University, Yekaterinburg, Russia

<sup>2</sup> Graduate Student, Assistant, Chair of Electrical Engineering and Electrotechnological Systems, Ural Federal University, Yekaterinburg, Russia

<sup>3</sup> Doctor of Technical Sciences, Professor, Chair of Electrical Engineering and Electrotechnological Systems, Ural Federal University, Yekaterinburg, Russia

E-mail: zyacho72@gmail.com

**Abstract.** Nowadays, one of the main economic advantages is using secondary raw materials for the production of useful materials for further use. The greatest environmental and economic effect provides the use of secondary non-ferrous metals. Eddy-current separation based on interaction force of a magnetic field with eddy currents induced by this field in conducting particles, is the most effective for the recycling of non-ferrous metals. The paper is devoted to the problem of non-ferrous metals sorting. The research results of the number of traveling magnetic field separators designs are described. The ways of improving separation efficiency are shown. Eddy-current separators can be used as stand-alone solutions, and in combination with shredder and classifying systems, in a variety of recycling plants and at metallurgical enterprises for non-ferrous metals refinement.

**Keywords:** separation, induction sorting of metals, research results.

### 1. Introduction

One of the trends in the development of the economy, which allows solving environmental and economic problems, is an increase in the production of secondary non-ferrous metals. When using secondary metals the need for mineral raw materials, energy consumption and emissions of pollutants into the biosphere are reduced. At the same time, thorough the sorting of collected scrap, which should ensure the production of high-quality secondary alloys with an admixtures level not higher than that of primary metal alloys, is becoming increasingly important. The uncontrolled mixing of a scrap of non-ferrous metals and their alloys in combination with the melt purification constraints during remelting creates big problems in obtaining high-quality alloys from secondary raw materials [1-4]. Therefore, the development and creation of technologies for the collection and processing of scrap and non-ferrous metal waste, as well as related technological equipment, are relevant.

Electrodynamic (eddy-current) separation is the most often method used for non-ferrous metals recovery from solid waste and also separating non-ferrous metals from each other [5-9]. Eddy-current separation is based on the force interaction of a magnetic field with eddy currents induced in



conducting particles using a time-varying field. An electromagnetic force ejects metal particles out of the stream of materials. A traveling or rotating magnetic field can be generated by three-phase linear inductors or rotating inductors based on permanent magnets [5, 9]. The most widespread, are separators based on permanent magnets [5-7]. At the same time, the possibilities of separators, based on three-phase linear inductors, are not well understood [5, 8-9].

The article presents the results of the research of eddy-current separators based on linear induction machines.

## 2. Decided technological problems

One of the fast-growing large-tonnage types of solid waste is automobile scrap. Therefore the problems of disposal of end-of-life vehicles require increased attention. The main commercial product of auto recycling is steel scrap. At the same time, in the automotive industry, there is a tendency to increase the share of light alloys (primarily aluminum) in the design of cars. For example, in the cars of the world's leading automobile companies, released in 2010, the share of aluminum reaches 15–20% (by weight) and its subsequent growth is forecast to be up to 30% [10–12]. The increase in the share of aluminum is accompanied by the expansion of the list of alloys used in the automotive industry. Therefore, in auto recycling, it is advisable to solve three consecutive technological tasks:

- the selection of non-ferrous metals from the flow of non-metals after shredding processing and magnetic separation;
- separation of non-ferrous scrap by types of alloys (aluminum, copper, zinc);
- division of aluminum scrap into groups and grades of alloys.

Similar technological problems also arise at metallurgical plants in the preparation of mixed non-ferrous scrap for melting [13].

Another fast-growing group of metal-containing waste is electronic scrap. Such waste can be a significant source for the extraction of not only non-ferrous but also precious metals [9, 14-15]. One of the important problems in the processing of crushed electronic scrap is the separation of aluminum and copper alloys. The collection of copper alloys in a separate group facilitates the subsequent separation of precious metals.

A significant proportion of waste containing non-ferrous metals (primarily copper and aluminum) is scrap and cable waste. In the manufacture of cables, technically pure highly conductive metals are used, as well as high-quality insulating materials (polymers, rubber). Powerful cables, in most cases, have a protective sheath (made of lead, aluminum or steel tape). One of the common technologies for processing cable scrap is its crushing, followed by separation of metal fractions and insulating materials [16-17]. The most important separation task is to improve the quality of copper or aluminum concentrates. Removal of impurities from such concentrates allows the secondary use of highly conductive metals for the production of cable products.

The literature analysis shows that electrodynamic separation is most often used to solve these technological problems.

## 3. Objects of research

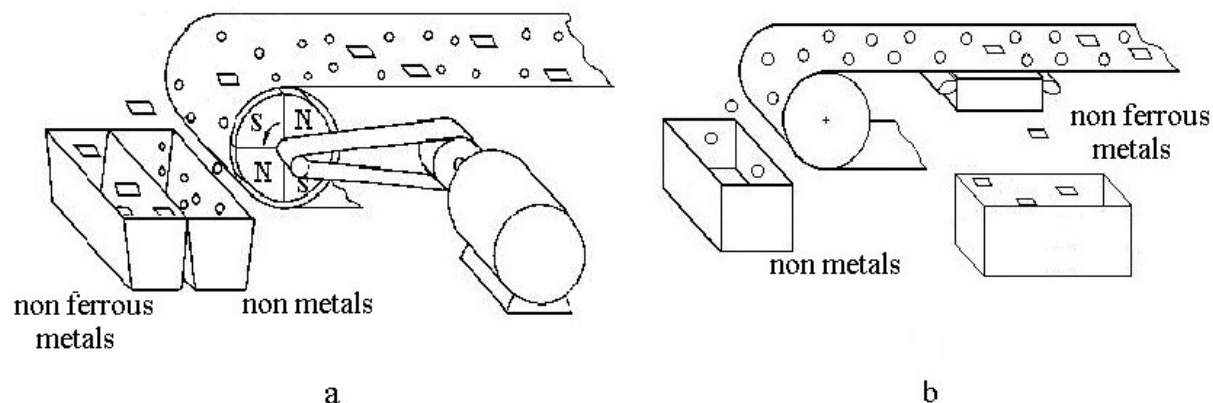
The presented technological tasks can be divided into two types:

- the extraction of non-ferrous metals from the flow of non-metals;
- sorting of non-ferrous metals by types and brands of alloys.

The tasks of the first type can be solved by using electrodynamic separators, schematically shown in figure 1. Both versions of separators are widely used in practice. The result of separation is most often a collective metal concentrate.

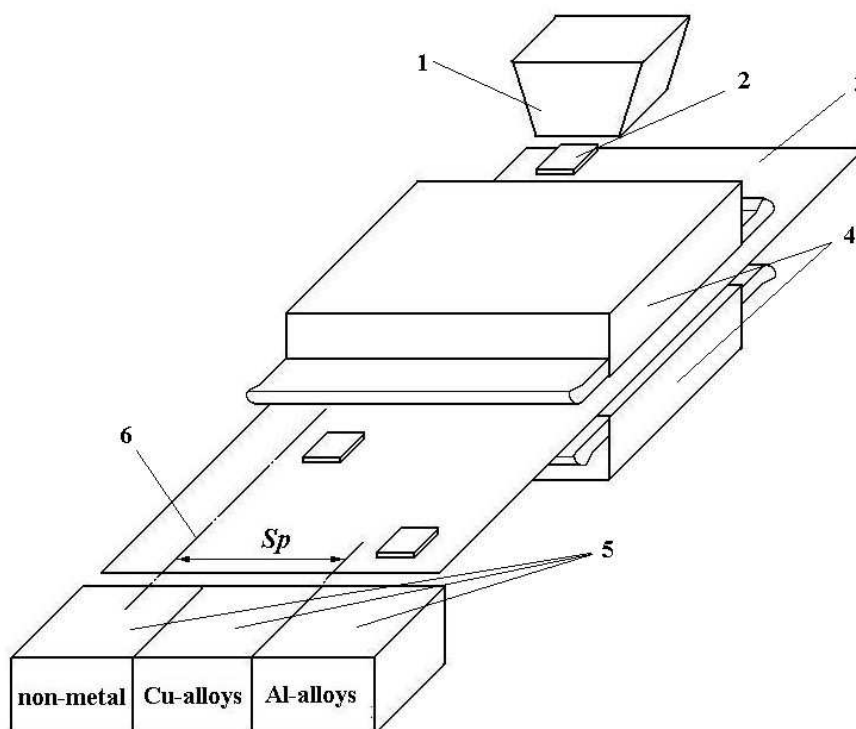
The separator shown in figure 1-a is characterized by low power consumption and can operate at increased frequencies of the magnetic field. At the same time, such a separator has a more complex structure and requires the supply of material in a thin layer, which causes a number of limitations. Separators based on three-phase linear induction machines (LIM) are easily integrated into complete

production lines and have great productivity. However, they operate at a frequency of 50 Hz, which makes it difficult to separate metal particles with a particle size of less than 40 mm.



**Figure 1.** Electrodynamic separators with magnetic rotor (a) and with linear induction machine (b)

For induction sorting of non-ferrous metals, the most important indicator is the selectivity of the separation of metals, which is difficult to ensure when feeding materials along the conveyor belt. Great opportunities to control the trajectories of particles of different metals and to increase the selectivity of separation appear when materials are fed into the working area along an inclined plane. An example of such a separator is shown in figure 2. To increase the electromagnetic forces, it is possible to use a LIM with a double-sided inductor. In this case, the size of the working gap is determined by the size of the separated particles.



**Figure 2.** Electrodynamic separator with double-sided linear induction machine:

- 1 – feed hopper; 2 – particle; 3 – feed plane; 4 – primary LIM;
- 5 – collection bins; 6 – feed line;  $Sp$  - splitter position

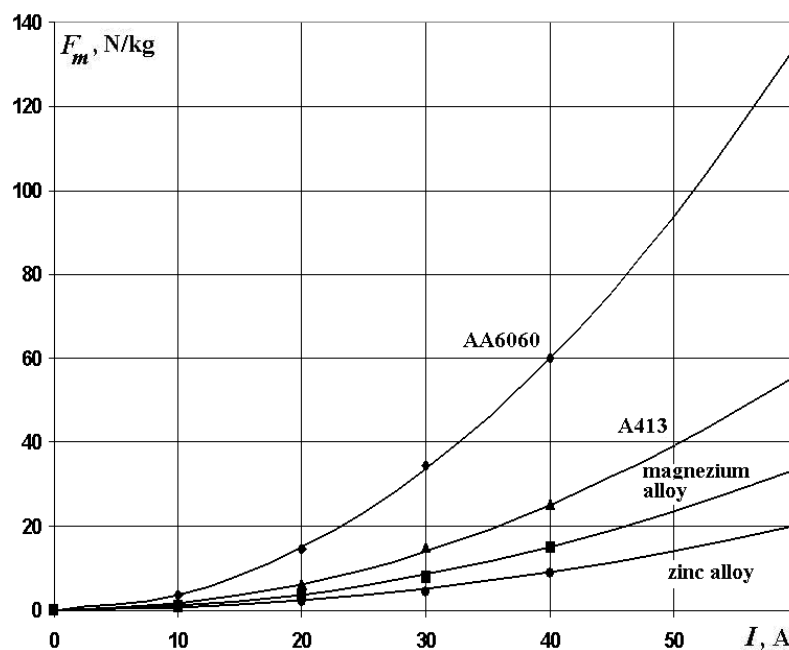
To increase the selectivity of metal separation, the separated materials are fed along a feed line in a narrow stream, the width of which is determined by the particle size.

In the research laboratory of the Ural Federal University, all types of facilities, shown in figures 1 and 2, were created. This allows a variety of studies of separation processes to solve various technological problems.

#### 4. Research results

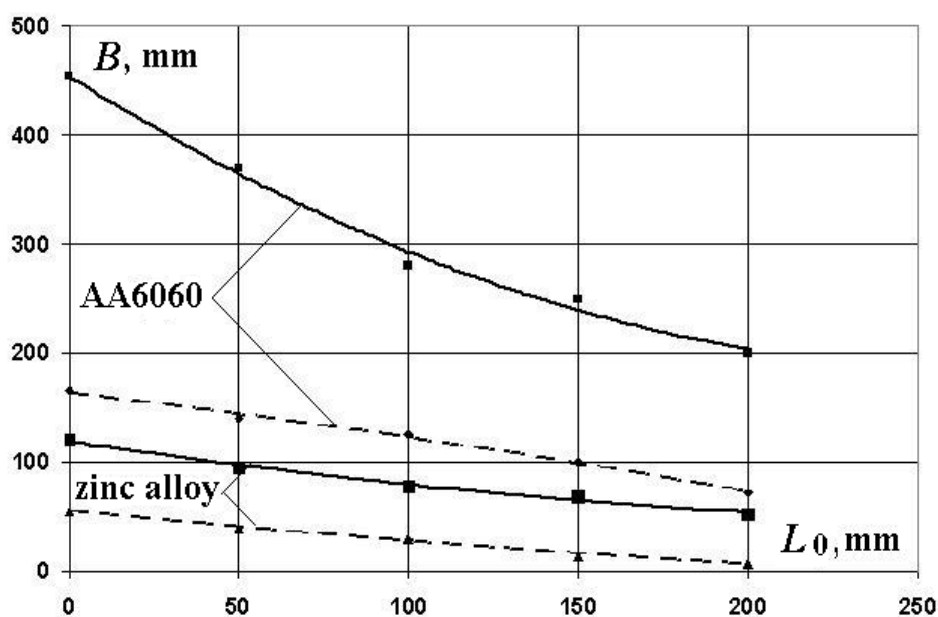
##### 4.1. Automobile scrap

A study of the processes of induction sorting of non-ferrous metals, represented in automobile scrap, was carried out on samples of aluminum alloys (cast or wrought), of magnesium and zinc alloys. At the first stage, the specific electromagnetic forces were evaluated (the ratio of the electromagnetic force to the particle mass, N/kg or  $\text{m/s}^2$ ). Figure 3 shows the dependences of such forces acting on plates with dimensions of  $40 \times 40 \times 3$  mm in a double-sided linear machine (pole pitch 0.18 m, air-gap 0.06 m) on the current in the separator. Experimental forces were obtained for currents from 0 to 40 A (at a rated current of laboratory installation of 30 A). The calculations were performed for currents up to 60 A, which can be achieved in an industrial installation with forced air cooling.



**Figure 3.** The dependence of the specific electromagnetic force on the LIM current: calculated (lines) and experimental (points)

A significant difference in forces for different alloys indicates the possibility of sorting. This is confirmed by testing the electrodynamic separator when feeding metals on an inclined plane. The total deflections of the metal particles from the feed line B at the outlet of the installation (at the end of the inclined plane) were measured depending on the distance from the input edge of the inductor to the starting point  $L_0$ . The measurements were performed at the rated currents of the installation (power consumption 1 kW). Figure 4 shows the dependences for two alloys in the range of particle sizes from 20 to 40 mm. It can be seen that there is a choice of the location of the flow splitter, which causes a collection of different alloys in different receivers. For example, at  $L_0 = 0.1$  m, the distance from the feed line to the splitter can be  $Sp = 0.1$  m.



**Figure 4.** Path deflections of particles of different alloys from the feed line, depending on the distance from the input edge of the inductor to the starting point for different particle size:  $40 \times 40$  mm - solid lines,  $20 \times 20$  mm - dotted lines

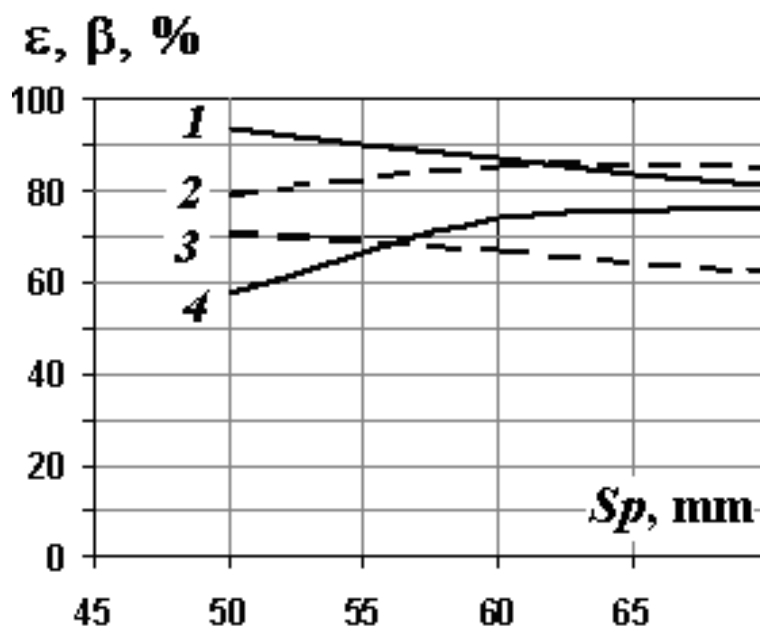
#### 4.2. Electronic scrap

For the separation of electronic scrap, an installation was used with feeding the material along an inclined plane based on a two-sided linear induction machine (power consumed by the inductor  $P = 750$  W, pole pitch 0.066 m, air-gap 0.020 m). During the tests, a large fraction of crushed electronic scrap with a particle size of 8 to 20 mm was used. The characteristics of the scrap sample are shown in table 1. The main purpose of separation is the separation of particles of aluminum alloys from copper alloys.

**Table 1.** Mass and volume indicators of the processed sample electronic scrap

Fractional composition	Mass part		Volume part	
	g	%	cm <sup>3</sup>	%
Aluminum alloys	273.00	60.67	101.11	79.83
Copper alloys	155.00	34.45	17.41	13.74
Other	22.00	4.88	8.14	6.43
Total	450	100	126.66	100

Figure 5 shows the dependences of the technological parameters of the separator on the position of the material flow splitter  $S_p$  achieved in one of the series of tests. Further studies show that separation indicators can be further improved.



**Figure 5.** Separation indicators (by weight): recovery (solid lines) and grade (dotted line): 1, 2 - for aluminum alloys (in concentrate); 3, 4 - for copper alloys (in tails)

#### 4.3. Cable scrap

When processing crushed cable scrap, electrodynamic separation is used to improve the quality of the base metal concentrate (copper or aluminum). For testing, we used a setup with feeding material along an inclined plane based on a two-sided linear induction machine (power consumed by the inductor  $P = 900$  W, pole pitch 0.066 m, air-gap 0.01 m). Samples of crushed cable scrap provided by enterprises consisted of particles with a particle size of 3 to 8 mm. The compositions of the samples of the starting aluminum concentrate are shown in table 2, and the source of copper concentrate in table 3.

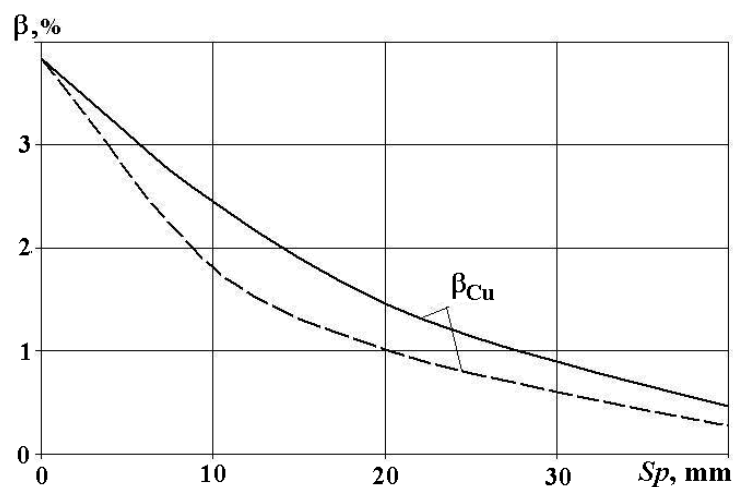
**Table 2.** Morphological composition of the sample of the starting aluminum concentrate

Material	Mass, g	Mass part, %
Aluminum	478.8	95.76
Copper	19.2	3.84
Insulation	2.0	0.40
Total	500.0	100.00

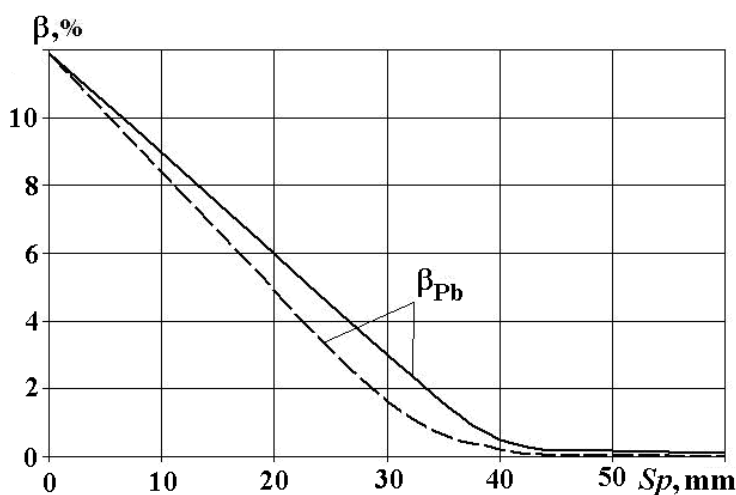
**Table 3.** Morphological composition of the sample of the starting copper concentrate

Material	Mass, g	Mass part, %
Copper	131.1	87.4
Lead	17.9	11.9
Insulation	1.0	0.7
Total	150.0	100.00

Some test results are shown in figures 6 and 7.



**Figure 6.** Reducing the proportion of copper in aluminum concentrate



**Figure 7.** Reducing the proportion of lead in copper concentrate

## 5. Conclusion

Summarizing all the facts, the performed research has shown the possibility of efficient separation of non-ferrous metals in solving various technical problems in installations based on double-sided linear induction machines when feeding material on an inclined plane.

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